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(71) Applicant: <b>DEPOTECH CORPORATION [US/US]; 11025 North Torrey Pines Road, La Jolla, CA 92037 (US).</b>			
(72) Inventors: <b>SANKARAM, Mantripragada; Apartment #53, 12726 Torrey Bluff Drive, San Diego, CA 92130 (US). KIM, Sinil; 548 Ford Avenue, Solana Beach, CA 92705 (US).</b>			
(74) Agents: <b>BOSTICH, June, M. et al.; Spensley Horn Jubas &amp; Lubitz, 5th floor, 1880 Century Park East, Los Angeles, CA 90067 (US).</b>			

**(54) Title:** VESICLES WITH CONTROLLED RELEASE OF ACTIVES**(57) Abstract**

A synthetic membrane vesicle composition containing at least one release-rate modifying agent other than a hydrohalide and at least one biologically active substance, the vesicles having defined size distribution, adjustable average size, internal chamber size and number, and a controlled release rate of the biologically active substance. A process for making the composition features addition of a release-rate modifying agent effective to prolong, sustain, and control the rate of release from the vesicles of the biologically active substance at therapeutic levels after encapsulation.

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## VESICLES WITH CONTROLLED RELEASE OF ACTIVES

### BACKGROUND OF THE INVENTION

#### 5 1. Field of the Invention

The invention relates to compositions of synthetic membrane vesicles useful as a drug delivery system and to processes for their manufacture.

#### 10 2. Background of the Invention

Multivesicular liposomes are one of the three main types of liposomes, first made by Kim, et al. (*Biochim, Biophys. Acta*, 782:339-348, 1983), and are uniquely different from other lipid-based drug delivery systems such as unilamellar (Huang, *Biochemistry*, 8:334-352, 1969; Kim, et al., *Biochim. Biophys. Acta*, 646:1-10, 1981) and multilamellar (Bangham, et al., *J. Mol. Bio.*, 13:238-252, 1965) liposomes. In contrast to unilamellar liposomes, multivesicular particles contain multiple aqueous chambers per particle. In contrast to multilamellar liposomes, the multiple aqueous chambers in multivesicular particles are non-concentric.

The prior art describes a number of techniques for producing unilamellar and multilamellar liposomes; for example, U.S. Patent No. 4,522,803 to Lenk; 4,310,506 to Baldeschwieler; 4,235,871 to Papahadjopoulos; 4,224,179 to Schneider; 4,078,052 to Papahadjopoulos; 4,394,372 to Taylor; 4,308,166 to Marchetti; 4,485,054 to Mezei; and 4,508,703 to Redziniak. The prior art also describes methods for producing multivesicular liposomes that proved unstable in biological fluids (Kim, et al., *Biochim. Biophys. Acta*, 728:339-348, 1983). For a comprehensive review of various methods of unilamellar and multilamellar liposome preparation, refer to Szoka, et al., *Ann. Rev. Biophys.* Bioeng., 9:465-508, 1980.

In the method of Kim, et al. (*Biochim. Biophys. Acta*, 728:339-348, 1983), the encapsulation efficiency

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of small molecules, such as cytosine arabinoside, was low, and had rapid release rate in biological fluids. Subsequent studies (Kim, et al., *Cancer Treat. Rep.*, 71:705-711, 1987) showed that the rapid release rate of 5 encapsulated molecules in biological fluids can be improved by encapsulating in the presence of a hydrochloride.

Optimal treatment with many drugs requires maintenance of a drug level for a prolonged period of time. For example, optimal anti-cancer treatment with 10 cell cycle-specific antimetabolites requires maintenance of a cytotoxic drug level for a prolonged period of time. Cytarabine is a highly scheduled-dependent anti-cancer drug. Because this drug kills 15 cells only when they are replicating DNA, a prolonged exposure at therapeutic concentration of the drug is required for optimal cell kill. Unfortunately, the half-life of Cytarabine after an intravenous (IV) or subcutaneous (SC) dose is very short, with the half-life in the range of a few hours. To achieve optimal 20 cancer cell kill with a cell cycle phase-specific drug like Cytarabine, two major requirements need to be met: first, the cancer must be exposed to a high concentration of the drug without doing irreversible 25 harm to the host; and second, the tumor must be exposed for a prolonged period of time so that all or most of the cancer cells have attempted to synthesize DNA in the presence of Cytarabine.

Heretofore, control of the release rate was 30 inflexible, and the choice of release-rate modifying agents was limited primarily to hydrohalides. For a drug-delivery system, it is highly advantageous to be flexible in controlling the release rate for 35 encapsulated substances and to have a wide choice of release-rate modifying agents.

Accordingly, it is an object of the present invention to provide a slow-releasing depot preparation

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which provides a prolonged and sustained exposure of a biologically active substance at a therapeutic concentration, with a controlled release rate.

It is a further object of the present invention to  
5 provide a method of preparing such depot preparations.

Other and further objects, features, and advantages  
of the invention are inherent therein and appear  
throughout the specification and claims.

10 **SUMMARY OF THE INVENTION**

The compositions of the present invention comprise synthetic membrane vesicles, i.e. lipid vesicles with multiple internal aqueous chambers formed by non-concentric layers and wherein the chambers contain one or more release-rate modifying agents effective in slowing the release rate of the encapsulated biologically active substances. The present invention also provides methods of making such compositions.

20 The present synthetic membrane vesicle compositions have high encapsulation efficiency, controlled release rate of the encapsulated substance, well defined, reproducible size distribution, spherical shape, adjustable average size that can be easily increased or decreased, adjustable internal chamber size and number.

25 The process for producing these compositions comprises (1) mixing one or more volatile organic solvents and a lipid component containing at least one neutral lipid and at least one amphipathic lipid having one or more net negative charges; (2) adding into the organic solvent an immiscible first aqueous component containing one or more biologically active substances to be encapsulated; (3) adding to either or both the organic solvent and the first aqueous component, a release-rate modifying agent effective in slowing the release rate of the encapsulated biologically active substances; (4) forming a water-in-oil emulsion from the two immiscible components; (5) immersing the water-

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in-oil emulsion into a second immiscible aqueous component; (6) dispersing the water-in-oil emulsion to form solvent spherules containing in them multiple droplets of the first aqueous component; and (7) 5 removing the organic solvents, such as by evaporation, from the solvent spherules to form the synthetic membrane vesicles. Addition of one or more release-rate modifying agents effective in slowing the release rate of the encapsulated biologically active substances 10 in biological fluids and *in vivo* is essential.

#### A BRIEF DESCRIPTION OF THE DRAWING

Figure 1 is a graph showing the rate of release of a drug from synthetic membrane vesicles suspended in 15 human plasma at 37°C. The symbols used indicate the release rate modifying agent employed and are identified in Table 2.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

The term "synthetic membrane vesicles" as used 20 throughout the specification and claims means man-made, microscopic lipid-vesicles consisting of lipid bilayer membranes, enclosing multiple non-concentric aqueous chambers. In contrast, unilamellar liposomes have a single aqueous chamber; and multilamellar liposomes 25 have multiple "onion-skin" type of concentric membranes, in between which are shell-like concentric aqueous compartments.

The term "solvent spherule" as used throughout the 30 specification and claims means a microscopic spheroid droplet of organic solvent, within which is multiple smaller droplets of aqueous solution. The solvent spherules are suspended and totally immersed in a second aqueous solution.

The term "neutral lipid" means oil or fats that 35 have no membrane-forming capability by themselves and lack a hydrophilic "head" group.

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The term "amphipathic lipids" means those molecules that have a hydrophilic "head" group and hydrophobic "tail" group and have membrane-forming capability.

5       The term "release-rate modifying agent" means molecules other than hydrohalides added during the process of making or manufacturing the synthetic membrane vesicles that are effective in either slowing or increasing the release rate of the encapsulated biologically active substances from the synthetic  
10      membrane vesicles.

Briefly, the method of the invention comprises making a "water-in-oil" emulsion by (1) dissolving amphipathic lipids in one or more volatile organic solvents for the lipid component, (2) adding to the  
15      lipid component an immiscible first aqueous component and a biologically active substance to be encapsulated, and (3) adding to either or both the organic solvent and the first aqueous component, a release-rate modifying agent effective in slowing the release rate  
20      of the encapsulated biologically active substances from the synthetic membrane vesicles, and then emulsifying the mixture mechanically.

In the emulsion, the water droplets suspended in  
the organic solvent will form the internal aqueous  
25      chambers, and the monolayer of amphipathic lipids lining the aqueous chambers will become one leaflet of the bilayer membrane in the final product. The emulsion is then immersed in a second aqueous component containing one or more nonionic osmotic agents and an  
30      acid-neutralizing agent of low ionic strength, such as a proton acceptor preferably selected from free-base lysine, free-base histidine, or a combination thereof. Then the emulsion is agitated either mechanically, by ultrasonic energy, nozzle atomizations, and the like,  
35      or by combinations thereof, to form solvent spherules suspended in the second aqueous component.

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The solvent spherules contain multiple aqueous droplets with the substance to be encapsulated dissolved in them. The organic solvent is removed from the spherules, preferably by evaporation of a volatile 5 solvent, for instance by passing a stream of gas over the suspension. When the solvent is completely removed, the spherules convert into synthetic membrane vesicles. Representative gases satisfactory for use in evaporating the solvent include nitrogen, helium, 10 argon, oxygen, hydrogen, and carbon dioxide.

The release-rate modifying agent is any molecule that is effective in slowing the rate of release of the encapsulated biologically active substances from the synthetic membrane vesicles in biological fluids and *in vivo*, with the result that the release rate of the 15 substances is slower than that from synthetic membrane vesicles produced in the absence of such a release-rate modifying agent. The release-rate modifying agents include, but are not limited to, perchloric acid, 20 nitric acid, formic acid, acetic acid, trifluoroacetic acid, trichloroacetic acid, sulfuric acid, phosphoric acid, and combinations thereof. The amounts of the release-rate modifying agents used is one effective to provide a prolonged, sustained, and controlled rate of 25 release at therapeutic levels of the encapsulated biologically active substances. For example, the concentration of the release-rate modifying agent in the the organic solvent or the first aqueous component to which it is added is in the range from about 0.1 mM 30 to about 0.5 M and preferably from about 10 mM to about 200 mM.

Many different types of volatile hydrophobic solvents such as ethers, hydrocarbons, halogenated hydrocarbons, or Freons may be used as the lipid-phase 35 solvent. For example, diethyl ether, isopropyl and other ethers, chloroform, tetrahydrofuran, halogenated

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ethers, esters and combinations thereof are satisfactory.

In order to prevent the solvent spherules from sticking to each other and to the vessel wall, it is preferred that at least 1 percent molar ratio of an amphipathic lipid with a net negative charge be included in the spherules, that the suspending second aqueous solution have a very low ionic strength, and, when an acid is used, that an agent for neutralizing the acid be added to the second aqueous solution to form a concentration of from about 0.1 mM to about 0.5 M therein to prevent coalescence of the solvent spherules to form a messy scum. In addition, one or more nonionic osmotic agents, such as trehalose, glucose, or sucrose, may optionally be used in the suspending aqueous solution to keep the osmotic pressure within and without the membrane vesicles balanced.

Various types of lipids can be used to make the synthetic membrane vesicles, and the only two requirements are that one amphipathic lipid with a net negative charge and a neutral lipid be included.

Examples of neutral lipids are triolein, trioctanoin, vegetable oil such as soybean oil, lard, beef fat, tocopherol, and combinations thereof. Examples of amphipathic lipids with net negative charge are cardiolipin, the phosphatidylserines, phosphatidylglycerols, and phosphatidic acids.

The second aqueous component is an aqueous solution containing low ionic strength solutes such as carbohydrates including glucose, sucrose, lactose, and amino acids such as lysine, free-base histidine and combinations thereof.

Many and varied biological substances and therapeutic agents can be incorporated by encapsulation within the synthetic membrane vesicles.

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The term "therapeutic agent" as used herein for the compositions of the invention includes, without limitation, drugs, radioisotopes, and immunomodulators. Similar substances are known or can be readily ascertained by one of skill in the art. There may be certain combinations of therapeutic agent with a given type of synthetic membrane vesicles that are more compatible than others. For example, the method for producing the synthetic membrane vesicles may not be compatible with the continued biological activity of a proteinaceous therapeutic agent. However, since conditions that would produce an incompatible pairing of a particular therapeutic agent with a particular dispersion system are well known, or easily ascertained, it is a matter of routine to avoid such potential problems.

The drugs that can be incorporated into the dispersion system as therapeutic agents include non-proteinaceous as well as proteinaceous drugs. The term "non-proteinaceous drugs" encompasses compounds that are classically referred to as drugs, such as mitomycin C, daunorubicin, vinblastine, AZT, and hormones. Of particular interest are anti-tumor cell-cycle specific drugs such as cytarabine, methotrexate, 5-fluorouracil (5-FU), floxuridine (FUDR), bleomycin, 6-mercaptopurine, 6-thioguanine, fludarabine phosphate, vincristine, and vinblastine.

Examples of proteinaceous materials that can be incorporated into the synthetic membrane vesicles are DNA, RNA, proteins of various types, protein hormones produced by recombinant DNA technology effective in humans, hematopoietic growth factors, monokines, lymphokines, tumor necrosis factor, inhibin, tumor growth factor alpha and beta, Mullerian inhibitory substance, nerve growth factor, fibroblast growth factor, platelet-derived growth factor, pituitary and hypophyseal hormones including LH and other releasing

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hormones, calcitonin, proteins that serve as immunogens for vaccination, and DNA and RNA sequences.

The following TABLE 1 includes a list of representative biologically active substances effective in humans that can be encapsulated in synthetic membrane vesicles in the presence of a release-rate modifying agent of the invention, and also includes biologically active substances effective for agricultural uses.

10

TABLE 1

	<u>Antiasthmas</u> metaproterenol aminophylline theophylline terbutaline norepinephrine ephedrine isoproterenol adrenalin	<u>Antiarrhythmics</u> propanolol atenolol verapamil  <u>Antianginas</u> isosorbide dinitrate	<u>Tranquilizers</u> chlorpromazine benzodiazepine butyrophenones hydroxyzines meprobamate phenothiazines thioxanthenes
15			
20			
25	<u>Cardiac glycosides</u> digitalis digitoxin lanatoside C digoxin	<u>Hormones</u> thyroxine corticosteroids testosterone estrogen progesterone mineralocorticoid	<u>Steroids</u> prednisone triamcinolone hydrocortisone dexamethasone betamethasone prednisolone
30	<u>Antihypertensives</u> apresoline atenolol chlorpheniramine captopril reserpine	<u>Antidiabetics</u> Diabenese insulin	<u>Antihistamines</u> pyribenzamine
35			diphenhydramine
40	<u>Antiparasitics</u> <u>Analgesics</u> praziquantel metronidazole pentamidine ivermectin synthetics	<u>Antineoplastics</u> azathioprine bleomycin cyclophosphamide vincristine	<u>Sedatives and</u> morphine dilaudid codeine codeine-like
45	<u>Nucleic Acids and Analogs</u> DNA RNA	methotrexate 6-TG 6-MP vinblastine	demerol oxymorphone phenobarbital barbiturates

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	methylphosphonates and analog	VP-16	fentanyl
	Antisense nucleic acids	VM-26	ketorolac
5		cisplatin	
		5-FU	
		FUDR	
		fludarabine phosphate	
10	<u>Antibiotics</u>	<u>Immunodulators</u>	<u>Vasopressors</u>
	penicillin	interferon	dopamine
	tetracycline	interleukin-2	dextroamphetamine
	amikacin	gammaglobulin	
	erythromycin	monoclonal antibodies	
	cephalothin		
	imipenem	<u>Antifungals</u>	<u>Antivirals</u>
15	cefotaxime	amphotericin B	acyclovir and derivatives
	carbenicillin	myconazole	Gancyclovir and phosphates
	ceftazidime	muramyl dipeptide	Winthrop-51711
	kanamycin	clotrimazole	ribavirin
	tobramycin	ketoconazole	rimantadine/amantadine
20	ampicillin	fluconazole	azidothymidine & derivates
	gentamycin	itraconazole	adenine arabinoside
	cefoxitin		amidine-type protease
	cefadroxil		inhibitors
	cefazolin		
25	other aminoglycosides		
	amoxicillin		
	moxalactam		
	piperacillin		
30	vancomycin		
	ciprofloxacin		
	other quinolones		
	<u>Vaccines</u>		
35	other recombinant, killed and live vaccines and antigenic material for use as vaccines.		
	antigenic material for the treatment of allergies		
	influenza		
	respiratory syncytial virus		
	HIV vaccine		
40	Hemophilus influenza vaccines		
	Hepatitis A,B,C vaccines		
	mumps		
	rubella		
	measles		
45	tetanus		
	malaria vaccines		
	herpes		
	cancer vaccines		
	Anti-leu-3a vaccine		
50	<u>Monoclonal Antibodies</u> (human, mouse other species-derived and/or recombinant and/ or fusions and/or fragments thereof)		
	OKT3		
	OKT4		
55	HA-1A		
	Anti-Carcino-Embryonic Antigen Antibodies		

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- Anti-Ganglioside Antibodies: Anti GD2, Anti GM2, Anti GD3, Anti GM3  
Urinary Tract-Associated Antigen-related antibodies  
Anti-IL-2 Receptor  
Chimeric Anti-Leu-2  
5 Anti-IL-2 receptor  
Anti-Leu-2  
Chimeric Anti-Leu-3a  
Chimeric L6  
MAb-L6  
10 Radiolabeled L6  
Centrex  
Centoxin  
Panorex  
Anti-LPS  
15 Immunotoxin  
Anti-tumor necrosis factor  
Anti-pseudomonas  
Anti-tumor necrosis factor  
OncoRad 103  
20 OncoScint CR103  
OncoScint OV103  
OncoScint PR356  
OncoTher 130  
KS 1/4-DAVLB  
25 ADCC agent  
Murine monoclonal antibodies to human B-cell lymphomas (anti-  
idiotypes)  
Murine monoclonal antibody (1Melpgl) (anti-idiotype) against murine  
monoclonal antibody to melanoma-associated antigen  
30 Anti-B4-blocked ricin  
Anti-My9-blocked ricin  
ImmuRaid-CEA  
MAb against colorectal, ovarian, and lung cancers  
rhenium-186 MAb  
35 Orthoclone OKT®  
E5™  
LYM-1  
TNT  
KomaZyme®-791  
40 KomaZyme®-CD5 Plus  
KomaZyme®-CD7 Plus  
KomaZyme®-Mel
- Herbicides
- 45 Triazine  
chloroacetamide  
cyanazine  
bentazone  
Roundup  
50 Rodeo  
butachlor  
CNP  
chlomethoxynil  
simetryne  
55 Atrazine  
Alachlor

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- Cyanazine  
metolachlor  
metribuzin  
phenoxy herbicides: 2,4-D [(2,4-dichlorophenoxy)acetic acid],  
5 2,4-D amine (2,4-dichlorophenoxyacetic acid dimethylamine),  
2,4-D isoctyl (2,4-dichlorophenoxyacetic acid isoctyl ester),  
2,4,5-T amine (2,4,5-trichlorophenoxyacetic acid trimethylamine)  
other triazine herbicides  
other chloroacetamide herbicides  
10 other phenoxyacid herbicides

- Pesticides
- Abamectin  
other avermectins  
15 atrazine  
lindane  
dichlorvos  
dimethoate  
warfarin  
20 p,p'-DDD  
p,p'-DDE  
HCH  
DMDT  
aldrin  
25 dieldrin  
Aldicarb  
EDB  
DCP  
DBCP  
30 simazine  
cyanazine  
Bacillus thuringiensis toxin  
Bacillus thuringiensis var. kurstaki  
bis(tri-n-butyltin)oxide (TBTO)  
35 other organochlorine pesticides

- Proteins and Glycoproteins
- lymphokines  
interleukins - 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11.  
40 cytokines  
GM-CSF  
M-CSF  
G-CSF  
tumor necrosis factor  
45 inhibin  
tumor growth factor  
Mullerian inhibitors substance  
nerve growth factor  
fibroblast growth factor  
50 platelet derived growth factor  
coagulation factors (e.g. VIII, IX, VII)  
insulin  
tissue plasminogen activator  
histocompatibility antigen  
55 oncogene products  
myelin basic protein

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- collagen
- fibronectin
- laminin
- other proteins made by recombinant DNA
- 5 technology
- erythropoietin
- IL-3/GM-CSF fusion proteins
- Monoclonal antibodies
- 10 Polyclonal antibodies
- antibody-toxin fusion proteins
- antibody radionuclide conjugate
- Interferons
- Fragments and peptide analogs, and analogs of fragment of proteins, peptides
- 15 and glycoproteins.
- Epidermal growth factor
- CD4 receptor and other recombinant receptors
- other proteins isolated from nature
- Antidiuretic hormone
- 20 oxytocin
- adrenocorticotropin Hormone
- calcitonin
- follicle stimulating hormone
- luteinizing hormone releasing hormone
- 25 luteinizing hormone
- gonadotrophin
- transforming growth factors
- streptokinase
- Human Growth Hormone,
- 30 Somatotropins for other species, including, but not limited to:
  1. Porcine,
  2. Bovine,
  3. Chicken,
  4. Sheep,
  5. Fish,
- 35 Growth Hormone releasing hormones for humans and various animal species,
- Glucagon,
- Desmopressin,
- 40 Thyroid Releasing Hormone,
- Thyroid Hormone,
- Secretin,
- Magainins,
- Integrins,
- 45 Adhesion Peptides, including, but not limited to, those having the Arginine-Glutamine-Aspartic Acid sequence,
- Super Oxide Dismutase,
- Defensins,
- T-Cell Receptors,
- 50 Bradykinin antagonists,
- Pentigetide,
- Peptide T,
- Antinflammins,
- Major Histocompatibility (MHC) complex components and peptides targeted to the MHC,
- 55 Protease inhibitors,

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Lypressin,  
Buserelin,  
Leuprolide,  
Nafarelin,  
5 Deslorelin,  
Goserelin,  
Historelin,  
Triptorelin,  
LHRH antagonists,  
10 HOE-2013,  
Detirelix,  
Org-30850,  
ORF-21243,  
Angiotensin Converting Enzyme inhibitor Peptide,  
15 Renin inhibitory peptides,  
Ebiratide (HOE-427),  
DGAVP,  
Opiate receptor agonists and antagonists, including, but not  
limited to:  
20 1. Enkephalins,  
2. Endorphins,  
E-2078,  
DPDPE,  
Vasoactive intestinal peptide,  
25 Atrial Natriuretic Peptide,  
Brain Natriuretic Peptide,  
Atrial Peptide clearance inhibitors,  
Hirudin,  
Oncogene Inhibitors,  
30 Other Colony Stimulating Factors,

	<u>Neurotransmitters</u>	<u>Radionuclides</u>	<u>Radio contrasts</u>
	Dopamine	Technetium	Gadolinium chelates
	Epinephrine	Indium	Iohexol
35	Norepinephrine	Yttrium	Ethiodol
	acetylcholine	Gallium	Iodexinol
	Gammaamino butyric acid		
	<u>Others</u>		
40	cell surface receptor blockers		

The term "therapeutically effective" as it pertains  
to the compositions of the invention means that a  
45 therapeutic agent is present in the aqueous phase  
within the vesicles at a concentration sufficient to  
achieve a particular medical effect for which the  
therapeutic agent is intended. Examples, without  
limitation, of desirable medical effects that can be  
50 attained are chemotherapy, antibiotic therapy, and  
regulation of metabolism. Exact dosages will vary

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depending upon such factors as the particular therapeutic agent and desirable medical effect, as well as patient factors such as age, sex, general condition, and the like. Those of skill in the art can readily 5 take these factors into account and use them to establish effective therapeutic concentrations without resort to undue experimentation.

Generally, however, the dosage range appropriate for human use includes the range of 0.1-6000 mg/sq m of body surface area. For some applications, such as 10 subcutaneous administration, the dose required may be quite small, but for other applications, such as intraperitoneal administration, the dose desired to be used may be very large. While doses outside the 15 foregoing dose range may be given, this range encompasses the breadth of use for practically all the biologically active substances.

The synthetic membrane vesicles may be administered for therapeutic applications by any desired route; for example, intramuscular, intrathecal, intraperitoneal, 20 subcutaneous, intravenous, intralymphatic, oral and submucosal, under many different kinds of epithelia including the bronchialar epithelia, the gastrointestinal epithelia, the urogenital epithelia, 25 and various mucous membranes of the body.

In addition the synthetic membrane vesicles of the invention can be used to encapsulate compounds useful in agricultural applications, such as fertilizers, pesticides, and the like. For use in agriculture, the 30 synthetic membrane vesicles can be sprayed or spread onto an area of soil where plants will grow and the agriculturally effective compound contained in the vesicles will be released by contact with rain and irrigation waters. Alternatively the slow-releasing 35 vesicles can be mixed into irrigation waters to be applied to plants and crops. One skilled in the art will be able to select an effective amount of the

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compound useful in agricultural applications to accomplish the particular goal desired, such as the killing of pests, the nurture of plants, etc.

The synthetic membrane vesicles may be modified in  
5 order to impart organ or cell target specificity, for instance by incorporating them into a targeted delivery system. Such modifications may be particularly relevant for using the synthetic membrane vesicles of the invention to administer drugs that are highly toxic  
10 or capable of inducing severe side effects, such as taxol.

The targeting of the synthetic membrane vesicles is classified based on anatomical and mechanistic factors.  
15 In anatomical targeting, the synthetic membrane vesicle is targeted to a specific body location, for example, organ-specific, cell-specific, and organelle-specific targeting. Mechanistic targeting can be distinguished based upon whether it is passive or active. Passive  
20 targeting utilizes the natural tendency of the synthetic membrane vesicles of the invention to distribute to cells of the reticulo-endothelial system (RES) in organs which contain sinusoidal capillaries. In active targeting, on the other hand, the synthetic  
25 membrane vesicle is incorporated into a targeted delivery system by coupling it to a specific ligand, such as a monoclonal antibody, sugar, glycolipid, or protein, or by changing the composition or size of the synthetic membrane vesicles in order to achieve targeting to organs and cell types other than the naturally occurring sites of localization (see, for example, *Remington's Pharmaceutical Sciences*, Gannaro, A.R., ed., Mack Publishing, 18 Edition, pp. 1691-1693, 1990)  
30  
35 In general, the compounds to be bound to the surface of the synthetic membrane vesicles will be ligands and receptors that allow the dispersion system

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to actively "home in" on the desired tissue. A ligand may be any compound of interest that will specifically bind to another compound, referred to as a receptor, such that the ligand and receptor form a homologous pair.

The surface of the targeted delivery system can be modified in a variety of ways. For instance, lipid groups can be incorporated into the lipid bilayer of the synthetic membrane vesicles in order to maintain the targeting ligand in stable association with the lipid bilayer. Various linking groups can be used for joining the lipid chains to the targeting ligand (Mannino, et al., *Bio Techniques*, 6(7):682, 1988). The compounds bound to the surface of the synthetic membrane vesicles may vary from small haptens of from about 125-200 molecular weight to much larger antigens with molecular weights of at least about 6000, but generally of less than 1 million molecular weight. Proteinaceous ligand and receptors are of particular interest.

In general, the surface membrane proteins that bind to specific effector molecules are referred to as receptors. In the present invention, the preferred receptors are antibodies. These antibodies may be monoclonal or polyclonal and may be fragments thereof such as Fab F(ab')<sub>2</sub>, and F<sub>v</sub>, which are capable of binding to an epitopic determinant. Techniques for binding of proteins, such as antibodies, to synthetic membrane vesicles are well known (see, for example, U.S. 4,806,466 and U.S. 4,857,735, incorporated by reference).

Antibodies can be used to target the synthetic membrane vesicles to specific cell-surface ligands. For example, certain antigens expressed specifically on tumor cells, referred to as tumor-associated antigens (TAAs) may be exploited for the purpose of targeting antibody-containing synthetic membrane vesicles

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directly to malignant tumors. Since the composition incorporated into the synthetic membrane vesicles may be indiscriminate with respect to cell type in its action, a targeted synthetic membrane vesicles offers a significant improvement over randomly injecting non-specific synthetic membrane vesicles. A number of procedures can be used to covalently attach either polyclonal or monoclonal antibodies to a bilayer of the synthetic membrane vesicles. Antibody-targeted synthetic membrane vesicles can include monoclonal or polyclonal antibodies or fragments thereof such as Fab, or F(ab')<sub>2</sub>, as long as they bind efficiently to the antigenic epitope on the target cells. Synthetic membrane vesicles may also be targeted to cells expressing receptors for hormones or other serum factors (Malone, et al., Proc. Nat'l. Acad. Sci., USA, 86:6077, 1989; Gregoriadis, Immunology Today, 11(3):89, 1990; both incorporated by reference).

The following examples illustrate the manner in which the invention can be practiced. It is understood, however, that the examples are for the purpose of illustration and the invention is not to be regarded as limited to any of the specific materials or conditions therein.

25

EXAMPLE 1

Step 1) In a clean glass cylinder (2.5 cm inner diameter X 10.0 cm height), 5 ml of a solution containing 46.5  $\mu$ moles of dioleoyl phosphatidylcholine, 30 10.5  $\mu$ moles of dipalmitoyl phosphatidylglycerol, 75  $\mu$ moles of cholesterol, 9.0  $\mu$ moles of triolein in chloroform were placed (the lipid phase).

Step 2) Five ml of aqueous phase, cytarabine (20 mg/ml) dissolved in 0.136 N perchloric acid, a release-rate modifying agent, is added into the above glass cylinder containing lipid phase. The osmolarity of the aqueous solution is about 274  $\pm$  20 mOs/kg. For the

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other release-rate modifying agents namely, nitric acid, formic acid, sulfuric acid, phosphoric acid, acetic acid, trichloroacetic acid, and trifluoroacetic acid, 20 mg/ml solutions of cytarabine were prepared with these agents to yield aqueous solutions that are nearly isotonic with respect to the final storage medium, namely normal saline (0.9% sodium chloride).

Step 3) For making the water-in-oil emulsion, a homogenizer (AutoHomoMixer, Model M, Tokushu Kika, Osaka, Japan) was used by mixing for 8 minutes at a speed of 9000 rpm.

Step 4) For making the chloroform spherules suspended in water, 20 ml of a solution containing 4 percent dextrose and 40 mM lysine was layered on top of the water-in-oil emulsion, and then mixed for 60 seconds at a speed of 4000 rpm to form the chloroform spherules.

Step 5) The chloroform spherule suspension in the glass cylinder was poured into the bottom of a 1000 ml Erlenmeyer flask containing 30 ml of water, glucose (3.5 g/100 ml), and free-base lysine (40 mM). A stream of nitrogen gas at 7 l/minute was flushed through the flask to slowly evaporate chloroform over 20 minutes at 37°C. 60 ml of normal saline (0.9% sodium chloride) was added to the flask. The synthetic membrane vesicles were then isolated by centrifugation at 600 X g for 10 minutes. The supernatant was decanted, and the pellet was resuspended in 50 ml of normal saline. The pellet was resuspended in saline to yield a final concentration of 10 mg Cytarabine per ml of suspension.

The average length-weighted mean diameter of the resulting synthetic membrane vesicles particles is in the range from 12-16  $\mu\text{m}$ . Percentage of capture of Cytarabine is given in TABLE 2. The use of different release-modifying agents had marked influence on the rate of Cytarabine release from the synthetic membrane vesicles incubated in human plasma. The percent of

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Cytarabine retained in the synthetic membrane vesicles after incubation at 37°C in human plasma for the different acids is plotted as a function of time of incubation in Figure 1. The half-life of drug release, calculated assuming a single-exponential model for the data shown in Figure 1, is given in TABLE 2. The data in TABLE 2 are the mean and standard deviation from three experiments.

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TABLE 2

		<u>Percent Capture of Cytarabine</u>	<u>Half-Life in Days for Release of Cytarabine</u>	<u>Symbol in Figure 1</u>
15	<u>Acid</u>			
20	Hydrochloric Acid	49 ± 5	65.7 ± 4.4	◆
	Perchloric Acid	45 ± 5	37.2 ± 8.0	▼
	Nitric Acid	44 ± 3	54.5 ± 5.7	■
	Phosphoric Acid	72 ± 1	6.5 ± 0.2	▲
	No Acid	46 ± 2	5.3 ± 0.5	●
25	Formic Acid	37 ± 2	5.6 ± 0.2	◇
	Trichloroacetic Acid	29 ± 1	5.5 ± 0.6	▼
	Acetic Acid	30 ± 2	4.8 ± 0.5	□
	Trifluoroacetic Acid	35 ± 1	3.4 ± 0.4	▲
30	Sulfuric Acid	57 ± 4	1.6 ± 0.5	○

It was surprising and unexpected that the nature of the acid had a profound effect on the release rates of cytarabine in human plasma. Use of monoprotic inorganic acids, namely, hydrochloric acid, nitric acid, and perchloric acid, resulted in the slowest release rate for cytarabine. Diprotic and triprotic acids, i.e., sulfuric acid and phosphoric acid, resulted in fast release rates. The organic acids, formic acid, acetic acid, trifluoroacetic acid and trichloroacetic acid, also resulted in fast release rates.

Thus, the present disclosure provides "depot" preparations of wide application and uses in which biologically active substances are encapsulated in

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biologically active substances are encapsulated in relatively large amounts, provide prolonged exposure or delivery at therapeutic concentrations of these substances for optimal results, and the release rate of 5 the substance is controlled by varying the nature of the acid used in the formulation.

The present invention, therefore, is well suited and adapted to attain the ends and objects and has the advantages and features mentioned as well as others 10 inherent therein.

While presently preferred embodiments of the invention have been given for the purpose of disclosure, changes may be made therein which are 15 within the spirit of the invention as defined by the scope of the appended claims.

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**CLAIMS**

1. A composition comprising a synthetic membrane vesicle comprising lipid bilayer membranes enclosing multiple non-concentric aqueous chambers containing one or more biologically active substance encapsulated therein and one or more non-hydrohalide release-rate modifying agents.
- 5 2. The composition of claim 1, wherein the release-rate modifying agents are selected from the group consisting of nitric acid, perchloric acid, formic acid, sulfuric acid, phosphoric acid, acetic acid, trichloroacetic acid, and trifluoroacetic acid, and salts or combinations thereof.
- 10 3. The composition of claim 1 wherein the release-rate modifying agent is a monoprotic inorganic acid.
4. The composition of claim 2, wherein the acids are neutralized with a proton acceptor.
- 15 5. The composition of claim 1 wherein the biologically active substance is a drug. substance.
- 20 6. The composition of claim 1 wherein the biologically active substances are selected from the group consisting of antibiotics, vaccines, antivirals, antifungals, anti-tumor drugs, proteins and glycoproteins.
- 25 7. A composition of claim 6 wherein the anti-tumor drug is cytarabine.
8. A composition of claim 1 wherein the biologically active substances are selected from the group consisting of herbicides and pesticides.
- 30 9. A targeted delivery system comprising a composition of Claim 1 with a targeting ligand attached thereto.
10. A targeted delivery system of claim 9 wherein the targeting ligand is an antibody or fragment thereof.
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11. A targeted delivery system of claim 9 wherein the antibody is a monoclonal antibody.
12. A targeted delivery system of claim 9 wherein lipid groups are incorporated into the lipid bilayer of the synthetic membrane vesicle.  
5
13. The composition of claim 1 wherein the synthetic membrane vesicle is anatomically targeted.
14. The composition of claim 1 wherein the synthetic membrane vesicle is mechanistically targeted.
- 10 15. The composition of claim 1 wherein the synthetic membrane vesicle is passively targeted.
16. The composition of claim 1 wherein the synthetic membrane vesicle is actively targeted.
17. The composition of claim 16 wherein the synthetic membrane vesicle is actively targeted by coupling  
15 with a moiety selected from the group consisting of a sugar, a glycolipid, and a protein.

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18. A synthetic membrane vesicle of claim 1 produced by the method comprising:
  - (a) forming a water-in-oil emulsion from two immiscible components containing at least one organic solvent, water, at least one biologically active substance, and at least one non-hydrohalide release-rate modifying agent;
  - (b) dispersing the said water-in-oil emulsion into an aqueous component to form solvent spherules; and
  - (c) removing the organic solvent from the solvent spherules to form the synthetic membrane vesicle.
19. A process for producing synthetic membrane vesicles comprising the steps of:
  - (a) forming a water-in-oil emulsion from two immiscible components containing at least one organic solvent, water, at least one biologically active substance, and at least one non-hydrohalide release-rate modifying agent;
  - (b) dispersing the water-in-oil emulsion into an aqueous component to form solvent spherules; and
  - (c) removing the organic solvent from the solvent spherules to form the synthetic membrane vesicles containing aqueous droplets with the biologically active substance and the release rate modifying agent dissolved therein..
20. The process of claim 19 wherein, the concentration of the non-hydrohalide release-rate modifying agent is present in the range of about 0.1 mM to about 0.5 M.
21. The process of claim 19 wherein, an acid neutralizing agent in a concentration of from about 0.1 mM to about 0.5 M is added during step (b).

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22. The process of claim 19 where, the organic solvent has a dissolved lipid component containing at least one amphipathic lipid with a net negative charge and at least one neutral lipid.
- 5 23. The process according to claim 22 wherein the lipid component is selected from the group consisting of a phospholipid and an admixture of phospholipids.
- 10 24. The process according to claim 23 wherein, the phospholipids are selected from the group consisting of phosphatidylcholine, cardiolipin, phosphatidylethanolamine, sphingomyelin, lysophosphatidylcholine, phosphatidylserine, phosphatidylinositol, phosphatidylglycerol, and phosphatidic acid.
- 15 25. The process according to claim 24 wherein, at least one of the phospholipids has at least one net negative charge.
- 20 26. The process according to claim 24 wherein, the phospholipid is provided in admixture with cholesterol.
27. The process according to claim 24 wherein, the phospholipid is provided in admixture with stearylamine.
- 25 28. The process according to claim 22 wherein, a lipophilic biologically active material is provided in admixture with the lipid component.
29. The process according to claim 22 wherein, the neutral lipid is selected from the group consisting of triolein, trioctanoin, vegetable oil, lard, beef fat, tocopherol, and combinations thereof.
- 30 35 30. The process according to claim 19 wherein, the organic solvent is selected from the group consisting of ethers, hydrocarbons, halogenated hydrocarbons, halogenated ethers, esters, and combinations thereof.

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31. The process according to claim 19 wherein, the biologically active material is hydrophilic.
32. The process according to claim 19 wherein, the emulsion is formed using a method selected from the group consisting of mechanical agitation, ultrasonic energy, and nozzle atomization.
- 5 33. The process according to claim 32 wherein, the average size of the synthetic membrane vesicles and number of the aqueous chambers therewithin are determined by the type, intensity, and duration of the emulsification method selected.
- 10 34. The process according to claim 19 wherein, the release rate modifying agent is a monoprotic inorganic acid, and aqueous component contains at least one neutralizing agent.
- 15 35. The process according to claim 34 wherein, the neutralizing agent is selected from the group consisting of free-base lysine, free base histidine, and a combination thereof.
- 20 36. The process according to claim 34 wherein, the aqueous component is an aqueous solution containing solutes selected from the group consisting of carbohydrates and amino acids.
- 25 37. The process according to claim 34 wherein, the aqueous component is an aqueous solution containing solutes selected from the group consisting of glucose, sucrose, lactose, free-base lysine, free-base histidine, and combinations thereof.
- 30 38. The process according to claim 19 wherein, the solvent spherules are formed using a method selected from the group consisting of mechanical agitation, ultrasonic energy, nozzle atomization, and combinations thereof.

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39. The process according to claim 38 wherein, the average size of the synthetic membrane vesicle is determined by the type, intensity, and duration of the energy used.
- 5      40. The process according to claim 19 wherein, the organic solvent is removed by passing gas over the aqueous component.
- 10     41. The process of Claim 19 wherein, the biologically active substance is selected from the group consisting of antiasthmas, cardiac glycosides, antihypertensives, antiparasitics, nucleic acids and analogs, antibiotics, vaccines, antiarrhythmics, antianginas, hormones, antidiabetics, antineoplastics, immunomodulators, 15     antifungals, tranquilizers, steroids, sedatives and analgesics, vasopressors, antivirals, monoclonal antibodies, herbicides, pesticides, proteins and glycoproteins, neurotransmitters, radionuclides, radio contrasts, and combinations thereof.
- 20     42. The synthetic membrane vesicle of claim 32 or 33 wherein, the biologically active substance is selected from the group consisting of antiasthmas, cardiac glycosides, antihypertensives, 25     antiparasitics, nucleic acids and analogs, antibiotics, vaccines, antiarrhythmics, antianginas, hormones, antidiabetics, antineoplastics, immunomodulators, antifungals, tranquilizers, steroids, sedatives and analgesics, vasopressors, antivirals, monoclonal antibodies, 30     herbicides, pesticides, proteins and glycoproteins, neurotransmitters, radionuclides, radio contrasts, and combinations thereof.

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43. A method for the treatment of a patient with a biologically active compound comprising:  
5 administering a therapeutic amount of a therapeutic agent to a patient encapsulated in a synthetic membrane vesicle in the presence of a non-hydrohalide release-rate modifying agent effective to control the rate of release of the compound at a therapeutic level.
44. A method for the treatment of a patient with a  
10 biologically active compound comprising:  
administering to the patient a synthetic membrane vesicle of claims 1, 2, 3, 4, 5, 6, 7, 8, 9, or 10.
45. The method of claim 19 wherein, the biologically active substance is selected from the group  
15 consisting of herbicides and pesticides.

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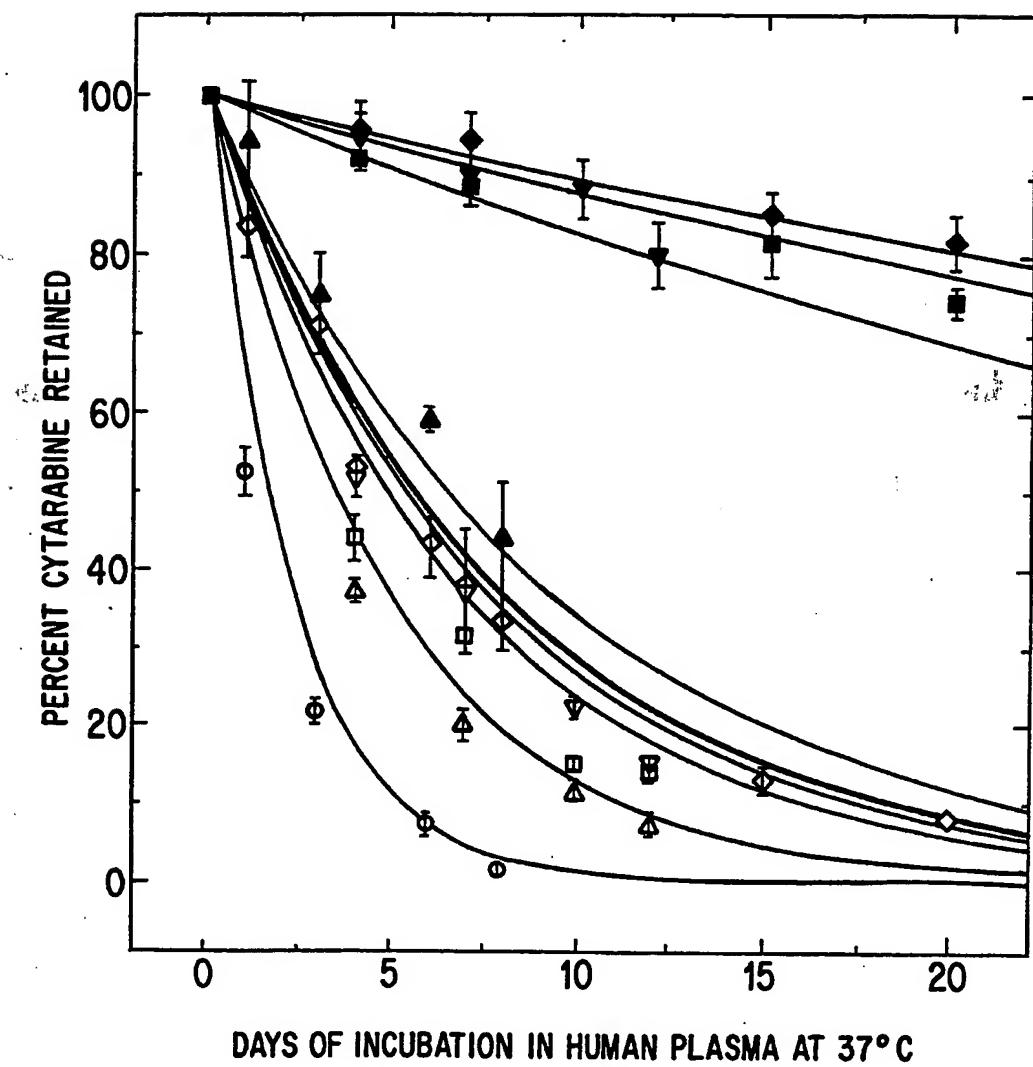


FIG. 1

## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/12957

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) :A61K 9/127  
 US CL :424/450

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/450, 417

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	CANCER RESEARCH 53, April 1, 1993 (KIM) "Prolongation of Drug Exposure in Cerebrospinal Fluid by Encapsulation into DepoFoam" pp. 1596-1598, see entire document.	1, 3-7, 9-10, 12-19, 21-26, 28, 30-44
Y	US, A, 4,310,506 (BALDESCHWIELER) 12 January 1982, see columns 3 and 4 and Examples II and III.	1, 19, 27
Y	US, A, 4,224,179 (SCHNEIDER) 23 September 1980, see columns 7-9.	1, 19, 27, 29
Y	US, A, 4,752,425 (MARTIN) 21 June 1988, see entire document.	19, 32
Y	US, A, 4,920,016 (ALLEN) 24 April 1990, see columns 4-22.	1, 11, 16, 17

<input checked="" type="checkbox"/>	Further documents are listed in the continuation of Box C.	<input type="checkbox"/>	See patent family annex.
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• Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
• "A" document defining the general state of the art which is not considered to be part of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
• "E" earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
• "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Z"	document member of the same patent family
• "O" document referring to an oral disclosure, use, exhibition or other means		
• "P" document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search	Date of mailing of the international search report
19 DECEMBER 1994	09 FEB 1995

Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer <i>Lenell Leach, Jr.</i> THURMAN K. PAGE Telephone No. (703) 308-2351
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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/12957

## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,211,955 (LEGROS) 18 May 1993, see entire document.	1, 2, 19, 20
Y	US, A, 4,588,578 (FOUNTAIN) 13 May 1986, see columns 6, lines 8-19 and column 13, lines 60-68.	8, 45